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METABK 59(2) 171-174 (2020)
UDC – UDK 669.715.3:66.04:620.17:536.5:620.18=111

HEAT TREATMENT T4 AND T6 EFFECTS ON MECHANICAL PROPERTIES IN AL-CU ALLOY AFTER REMELT WITH DIFFERENT POURING TEMPERATURES

Received – Primljeno: 2019-08-21
Accepted – Prihvaćeno: 2019-10-25
Original Scientific Paper – Izvorni znanstveni rad

Untreated alloy in cast-samples showed that hardness increases with increased pouring temperatures, while for samples after heat treatment (T4 and T6), the hardness value decreased with increased pouring temperatures. Tensile strength generally increases with heat treatment T4 and T6, but the influence of the temperature on the pouring tensile strength values initially presents high then decreases, then increases again. Impact energy increases after heat treatment T4 and T6. The distribution of precipitates in grain structure results in improved material properties such as hardness, tensile strength, and impact strength compared to when precipitates gathered at the grain boundary.

Key word: Al-Cu alloy; heat treatment; mechanical properties; pouring temperature; microstructure

INTRODUCTION

Aluminum has been widely used in various industries due to excellent corrosion resistance, high thermal conductivity, good machinability, as well as good metal formation and centrifugal casting [1]. Aluminum has a shiny silver color, and the color changes to light gray when placed in the open air due to the oxide layer. The melting temperature of pure aluminum is 660 °C, while the melting point of aluminum alloys range from 520 to 660 °C. Aluminum is also a metal alloy that is easily produced and recycled.

Aluminum alloy 2024 is an aluminum alloy with copper as the primary alloy. The composition of aluminum alloy 2024 consists of Al 90,7 - 94,7 %, Cu 3,8 - 4,9 %, and Mg 1,2 - 1,8 % [2]. This alloy widely is used in aircraft structural applications due to low density, high fracture toughness, and fatigue strength [3-8]. Although the 2024 aluminum alloy is used in aircraft structures, there are still some deficiencies in mechanical properties, so heat treatment is needed to improve these properties. These improvements can be achieved through a heat treatment [9] or a shot peening treatment [10].

Aluminum alloy 2024 can be strengthened through heat treatment, which is conducted by heating, holding, and quenching alloys in order to increase mechanical properties such as hardness, strength, ductility, and toughness [2]. Heat treatment consists of: (i) a metal alloy occur intermetallic Al_2Cu phase dissolution; (ii) quenching at room temperature, to obtain a supersaturated solid solution; (iii) age hardening, to obtain the precipitate of saturated solid solutions at room temperature such as natural aging (T4) and at high temperatures known as artificial aging (T6) [9,11]. The purpose of this experiment is to investigate the index of hardness, ultimate tensile strength, impact toughness, and microstructure evolution of alloy 2024 after remelting by three variations of pouring temperature.

MATERIAL AND EXPERIMENTAL METHODS

A piece of 2024 alloy in a cylindrical shape was cut into small pieces then melted in melting furnace, then cast into plate-shape mold. There were three pouring temperatures used in this study, 688, 738, and 788 °C, (± 3 °C), while the mold temperature was kept constant at 220 °C [12]. Brinell hardness testing was performed on each cast sample with a load of 613 Kgf for 30 seconds and an indenter diameter of 2,5 mm (ten times indentation). Tensile tests were carried out on cast samples with dimensions following the ASTM (E8) standard as shown in Figure 1. Tensile testing was carried out at room temperature using a universal testing machine and data taken at three different times. The Charpy impact test was performed at room temperature and dimensions of sample were based on ASTM 23. V-notch impact specimen had 45 ° notch with a radius of 2 and 0,2 mm, dimensions of impact specimen is 55 x 10 x 10 mm with three times repeated (Figure 2).

The hardness, tensile, and impact samples were heat treated by T4 and T6. All samples were placed in an electric furnace, heated at 510 °C then held at that tem-

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perature for 2,5 hours to ensure the β phase was dissolved in the α phase. Samples were then quenched in the water (± 25 °C) for heat treatment T4. Furthermore, samples were reheated at 190 °C for 10 hours (artificial aging/T6 heat treatment). Finally, all samples were placed in the open air. Microstructure was observed in cast products using an Olympus optical microscope. Samples were prepared by grinding with sandpaper, then polished and etched (using 3 ml of HF + 100 ml of distilled water).

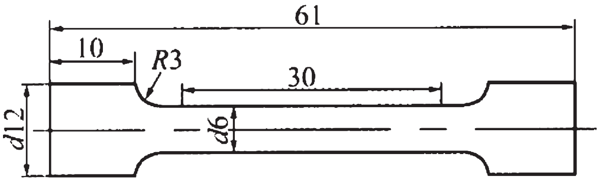


Figure 1 ASTM tensile sample /mm.

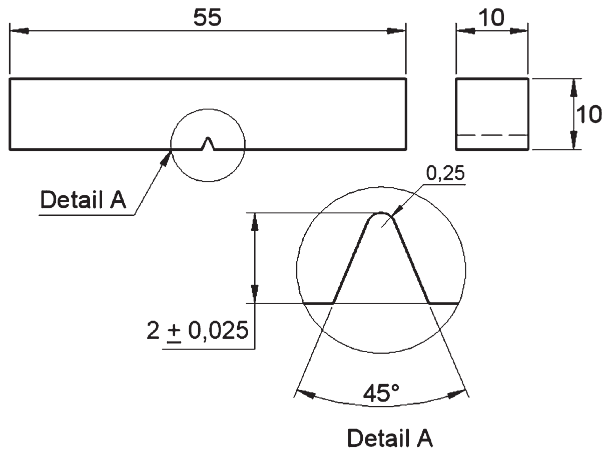


Figure 2 Schematic of impact specimen /mm.

RESULTS AND DISCUSSION

The chemical composition of casting products is shown in Table 1. Figure 3 shows the Brinell hardness obtained from cast-samples. The hardness of non-treated samples increases with higher pouring temperatures, whereas after the heat treatment process for T6 and T4, the hardness decreases with increased pouring temperature. The highest hardness value is 99,89 HB at 788 °C. The highest hardness index after T4 heat treatment shows 120,12 HB at 688 °C and 135,97 HB after T6 is 99,89 HB at 688 °C. In this case, a precipitation-hardened light alloy is very small and uniformly distributed in the Guinier-Preston zone (GP) and plate-shaped precipitation (θ" + θ') which serve as a hindrance to the dislocation movement. Precipitation formed in the interior of the Al grain in heat treatment thus strengthens the material, and this phenomenon is generally referred to as strengthening precipitation. In general, precipitation in Al-Cu alloys begins with the formation of solute groups (1 - 2 nm), which sequentially evolve into GP→θ"→θ'→θ phase [13-14]. T4 heat treatment shows that Al_2Cu precipitates spread in granules, where-

Table 1 **The chemical composition of casting products /wt.%.**

Cu	Mg	Mn	Fe	Al
4,69	1,13	0,95	0,56	Balance

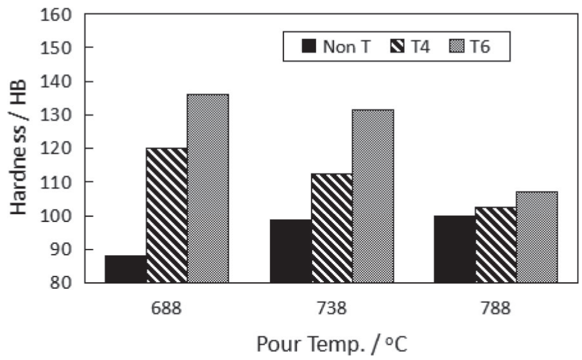


Figure 3 Brinell hardness with three variations of pouring temperature.

as the Al_2Cu precipitates are present around the grain boundaries for T6 artificial aging.

The investigation of the effect of the pouring temperature on tensile strength was carried out on untreated T4 and T6 cast samples as shown in Figure 4. Ultimate tensile strength (UTS) initially decreased from 156 MPa to 74 MPa and then increased to 98 MPa, with increased pouring temperature on casting specimens. However, the highest UTS value is 156 MPa at 688 °C of pouring temperature, and the lowest UTS value is 74 MPa at 738 °C. The results confirmed that pouring temperatures has an effect on the UTS of the cast sample. The overall UTS value for untreated (NT) specimens is lower than the maximum UTS.

The study of the heat treatment effects of T4 and T6 on aluminum alloys also shows influence on UTS values. The tensile index on T4 shows an increase in UTS values for all cast sample conditions. The UTS value increased from 156 to 247 MPa (an increase of 58,33 %) when the pouring temperature was 688 °C. With a pouring temperature of 738 °C, the UTS increased from 74 to 137 MPa (an increase of 85,13 %). The UTS value increased from 98 to 235 MPa (158,16 % increase) at a pouring temperature of 788 °C. The T6 tensile samples showed an increase in UTS values for all conditions. The UTS value increased from 156 to 275 MPa (an increase of 76,28 %) with a pouring temperature of 688 °C. The value of UTS saw an increase from 74 to 153 MPa (an increase of 106,75 %) at a pouring temperature of 738 °C and at 788 °C, the UTS value increased from 98 to 136 MPa (an increase of 38,77 %).

The effect of pouring temperature on the UTS samples after T4 heat treatment shows a decrease at low temperatures, the UTS value dropped from 247 to 137 MPa (from 688 to 738 °C), while the UTS value increased to 235 MPa at the pouring temperature of 788 °C. The UTS maximum is 247 MPa at a 688 °C pouring temperature, and the minimum is 137 MPa of 738 °C. The T6 heat treatment shows a decrease in the initial

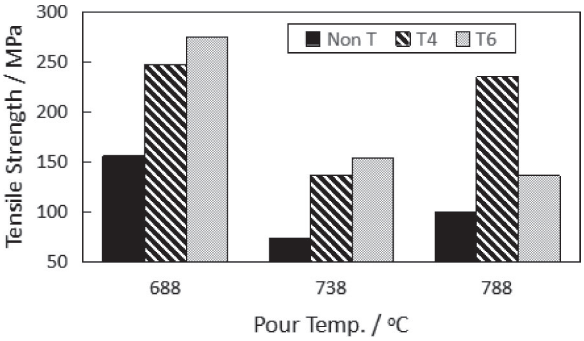
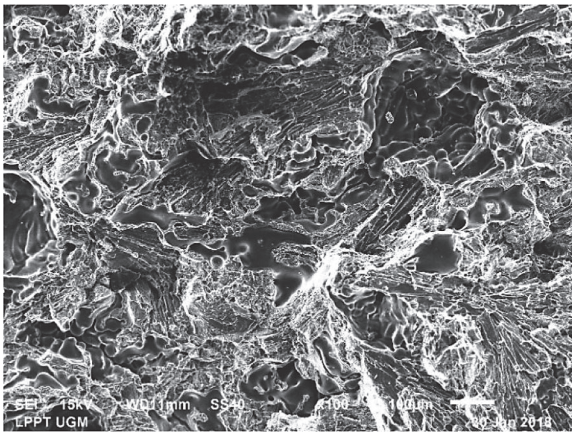
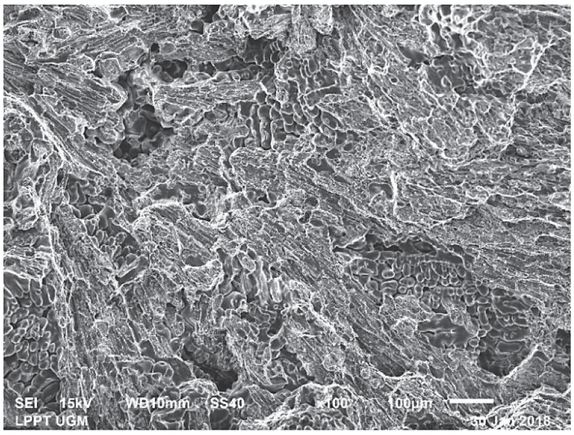


Figure 4 UTS with differences in pouring temperatures.



(a)



(b)

Figure 5 Scanning Electron Microscope (SEM) of heat treatment: (a) T4, and (b) T6.

cast temperature, the UTS value drops from 275 to 136 MPa (from 688 to 788 °C temperatures). The maximum of the UTS value is 275 MPa at a 688 °C, and the minimum index is 136 MPa at 788 °C.

The precipitate of Al_2Cu that occurred in the heat treatment cast-sample can strengthen the metal alloy. Maximum reinforcement can occur due to balanced formations of coherent constants, each semi coherent θ” and θ’ Al_2Cu precipitates [15-16]. Besides that, artificial aging causes a reduction in porosity, as shown in Figure 5.

Impact energy increases after the heat treatment of T4 and T6. An increase of impact energy is caused by the heat treatment and the material becomes brittle, so the T4 heat treatment presents the highest impact energy (Figure 6). The distribution of precipitates in granules results in increased material toughness compared with precipitates gathered at the edges of the granules. The highest impact energy is 8,259 J/mm^2 at a pouring temperature of 688 °C. There was a decrease in impact energy on the sample, and the highest value was 8,302 J/mm^2 when poured at 738 °C. The lowest impact energy was found in the sample that was poured at 788 °C, and it was 8,253 J/mm^2.

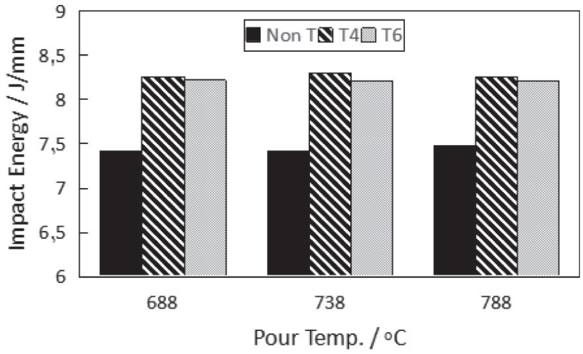


Figure 6 Energy impact with the variation of pouring temperature.

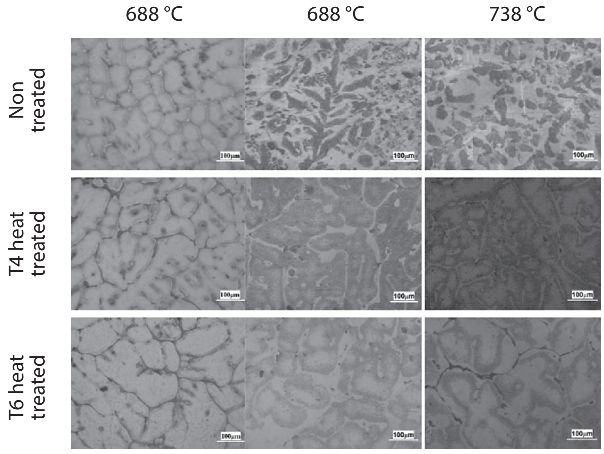


Figure 7 Microstructures with pour temperature difference and T4-T6 heat treatment.

Figure 7 shows the grain size smaller at a pouring temperature of 688 °C than at 738 and 788 °C. Differences in grain size are due to different solidification ranges and so are affected by differences of grain nucleation. The pouring temperature of 788 °C has a longer solidification time compared to temperature pouring at 738 °C and 688 °C. The T4 heat treatment shows Al_2Cu precipitate spreads in granules while in T6 heat treatment occurs at the boundaries of granules.

CONCLUSIONS

This experiment investigated the effects of three different pouring temperatures before and after T4 and T6 heat on the index of hardness, ultimate tensile strength, impact toughness and microstructure evolution of alloy 2024 after remelt. It can be concluded that the hardness cast-sample increases with increased pouring temperatures for untreated samples. Subsequently, for the sample after T4 and T6 heat treatment, the hardness value decreases with increased pouring temperature. Tensile strength generally increases with T4 and T6 heat treatments. Regarding the effects of the temperature while the material was being poured, the initial tensile strength is high, then decreases, then increases again with increased pouring temperature. Impact energy increases after heat treatment T4 and T6, but the pouring temperatures do not significantly affect impact energy. The increase occurs because the heat treatment causes the material to be brittle. Heat treatment T4 shows the highest impact energy. Microstructure observation showed that the Al_2Cu precipitate in T4 heat treatment spreads in granules. The T6 heat treatment causes Al_2Cu precipitates to gather around the edges of the granules.

Acknowledgments

This work is supported by the Research Fund of Hibah RTA Universitas Gadjah Mada.

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Note: The responsible translator for language English is Sydney Garvis - Language Center of Universitas Syiah Kuala, Indonesia.